ABSTRACT

A Millimeter Wave Propagation Experiment
From the ATS-E Spacecraft

by

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Instrumentation is described which will be used for performing a millimeter wave propagation experiment from the fifth Applications Technology Satellite (ATS-E). Wideband signals near 15.3 and 31.65 GHz will be transmitted between the spacecraft and several gro d stations, and attenuation and phase distortion effects caused by the atmosphere and meteorological phenomena (including rainfall) will be measured at the receiving terminals. The overall objective is to obtain propagation data at varied ground locations for a wide variety of weather conditions, including seasonal variations. The 15.3 GHz spacecraft signal is to be provided by a very stable solid state source which produces a total output power of approximately 200 milliwatts and which can be phase modulated at a rate of 0.1, 1, 10, or 50 MHz, producing a carrier and two significant sidebands nearly equal in level to the carrier. The 31.65 GHz ground transmitters will provide 100 to 200 watts output and will be capable of being modulated at 1, 10, or 50 MHz to provide two significant sidebands in addition to the carrier. The spacecraft receiver utilizes a superheterodyne system which employs dual mixers for redundancy. The receiver output is fed through a signal processor which performs measurements on the phase and amplitude of the received signals.

The satellite is to be placed at a stationary location above the Pacific Ocean in a synchronous orbit. The spacecraft antennas will have beamwidths of approximately 20 degrees, sufficient to subtend the full earth, including allowances for the librations of the gravity-gradient stabilization system.

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Millimeter wave frequencies offer a promising area for future space communication and data links because of such advantages as: wide bandwidth capabilities, plasma penetration capability, reduced spectrum crowding, potential for private or secure links, high-gain/small-aperture antenna characteristics, and reduced size and weight of components.

The propagation parameters of interest in earth-space millimeter wave links include atmospheric absorption, refraction, dispersion, fading, and noise considerations. Associated with these parameters is the propagation medium bandwidth limitation, which is of paramount interest for very wideband communication systems. The propagation characteristics in the millimeter band are significantly different than at lower frequencies, primarily because of oxygen and water vapor absorption. Figure 1 illustrates this effect for various elevation angles and for frequencies up to 100 GHz.

The National Aeronautics and Space Administration (NASA-GSFC) plans to conduct a millimeter wave propagation experiment from the fifth Applications Technology Satellite (ATS-E), for which a launch date in the first quarter of 1969 is planned. The objective of the experiment is to statistically determine the propagation parameters that are important in characterizing wideband earth-space communication or data links at K_u and K_a bands. This objective will be accomplished by transmitting signals (at 15.3 and 31.65 GHz) between

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a synchronous altitude satellite and various earth terminals over a period long enough to include seasonal changes. Correlating the measured propagation effects with weather conditions derived from radiometric and radar measurements will permit the performance of future links to be predicted under various weather conditions.

The ATS-E spacecraft will be gravity-gradient stabilized so that the millimeter wave horn antennas are always pointed toward the earth. Each horn will have a beamwidth of 20 degrees which is sufficient to subtend the entire earth (including allowances for satellite instabilities) from synchronous altitude. Present plans are for a stationary synchronous satellite location of 150 degrees west longitude.

The millimeter wave equipment to be used in the satellite is shown in Figure 2a (a 15.3 GHz down-link and a 31.65 GHz up-link). To complete the propagation test links, certain millimeter wave ground stations will be equipped with 15.3 GHz receivers and 31.65 GHz transmitters, as shown in Figure 2b. Several sites in the United States will be used, including locations in California, Texas, and Ohio. In addition, a transportable station is planned for use in Hawaii. All of the participating ground stations will be able to receive the 15.3 GHz signals simultaneously, since the transmitter will be in the satellite. However, for the 31.65 GHz uplink the ground stations must transmit sequentially.

The experiment will provide information on the coherence bandwidth of the atmospheric medium by transmitting a phase modulated carrier, from the satellite. A phase modulation index of 1.43 is employed which provides equal carrier and first sideband amplitudes, with little power wasted in higher order sidebands. Modulation rates of 100 kHz, 1 MHz, 10 MHz, or 50 MHz may be chosen

resulting in a carrier and two sidebands at any one time. An up-converter modulation technique (excluding the 100 kHz modulation rate) will be used in the up-link transmitter. At the 50 MHz modulation rate, the sideband separation will be 100 MHz so that wideband channel characteristics can be determined. In addition, the unmodulated carrier (CW signal) will be transmitted if an increased SNR is desired. Propagation parameters will be determined by measuring the individual signal amplitudes and the difference in the phase differentials between each sideband and the carrier. Phase locked tracking receivers will be used for both the up-link and the down-link with narrow individual channel bandwidths. Ground commands, via the ATS telemetry link (i.e., from the Mojave, California, telemetry station) will select the modulation rate (or no modulation) for the 15.3 GHz down-link. The ground receiver-signal processor will separate the carrier and sidebands, perform amplitude and phase measurements, and provide outputs to the data reduction equipment (down-link). Up-link measurements made by the spacecraft receiver-signal processor will be sent to the ground via the ATS telemetry link.

The up-link superheterodyne receiver derives its local oscillator power from the down-link transmitter (see Figure 2a). A portion of the transmitter power is coupled off and multiplied to twice the down-link frequency. The resulting 30.6 GHz LO is used to drive a balanced mixer (see Figure 3) which converts the 31.65 GHz up-link signal to an IF of 1.05 GHz. A balanced mixer is used for redundancy to improve reliability rather than to improve the noise figure. (A single-ended mixer could provide good noise figures at a microwave IF).

The entire spacecraft millimeter wave package, including antennas, K_u-band transmitter, K_a-band receiver and signal processor, weighs about 30 pounds, consumes about 30 watts, and is less than one cubic foot in volume. Figure 4 is a photograph of the engineering model. An all solid-state transmitter is used which provides 200 milliwatts of CW power at K_u-band and 60 milliwatts per spectral line when phase modulated. A down-link system dynamic range of over 20 dB is expected. Because the all solid-state transmitter represents state-of-the-art equipment, an alternate transmitter has also been developed using a klystron, solid-state power supply, and employing injection-locking for stabilization. Should unforeseen problems develop with the solid-state transmitter, the klystron transmitter will be substituted before the satellite is launched.

The up-link will employ 100 to 200 watt ground transmitters, permitting a dynamic range of over 40 dB at K_a-band. Both the up-link and down-link power levels should permit adequate measurements during even heavy rainfall conditions.

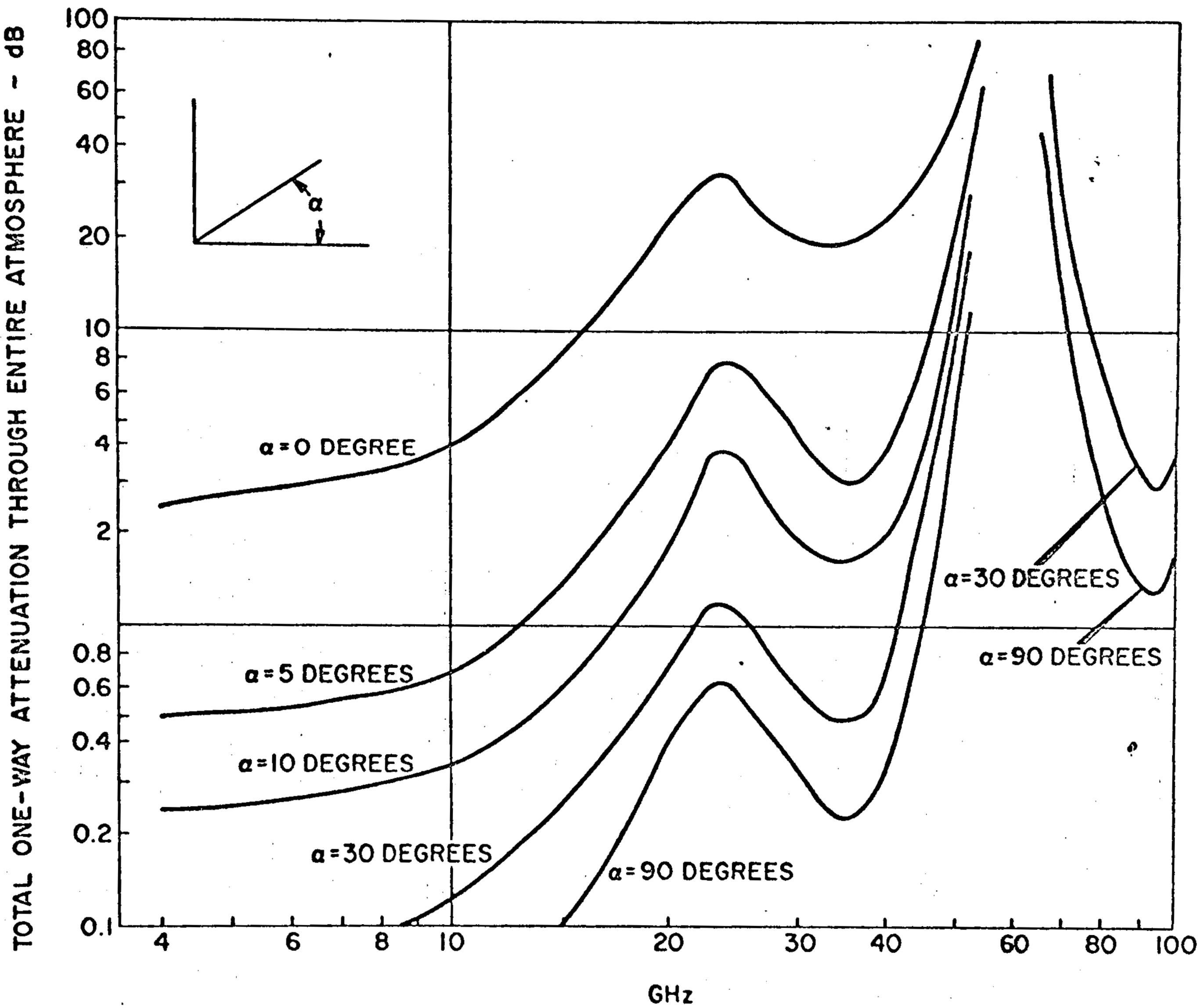

Figure 1. Absorption, Standard Atmosphere, Slant Path

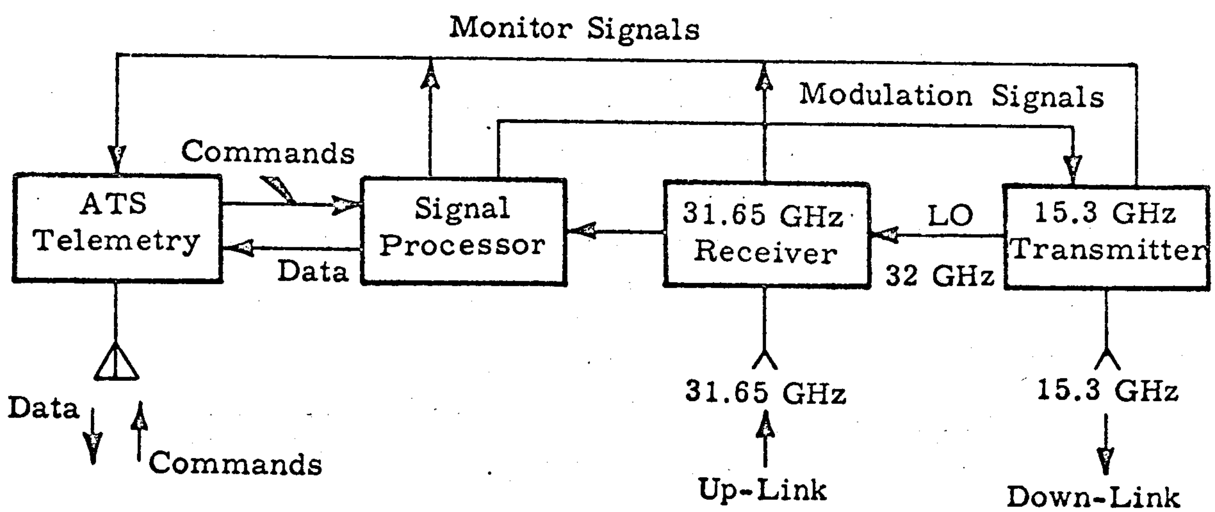

Figure 2a. ATS-E Millimeter Wave Satellite Equipment

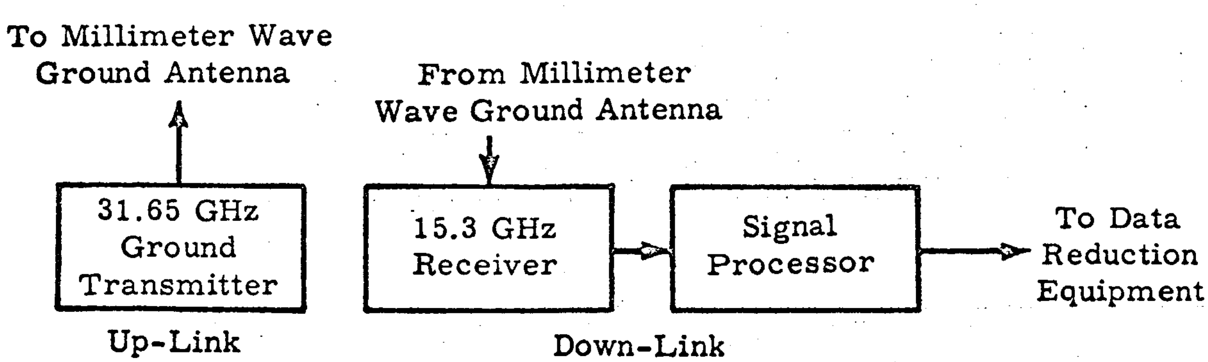

Figure 2b. Typical Millimeter Wave Ground Terminal Equipment

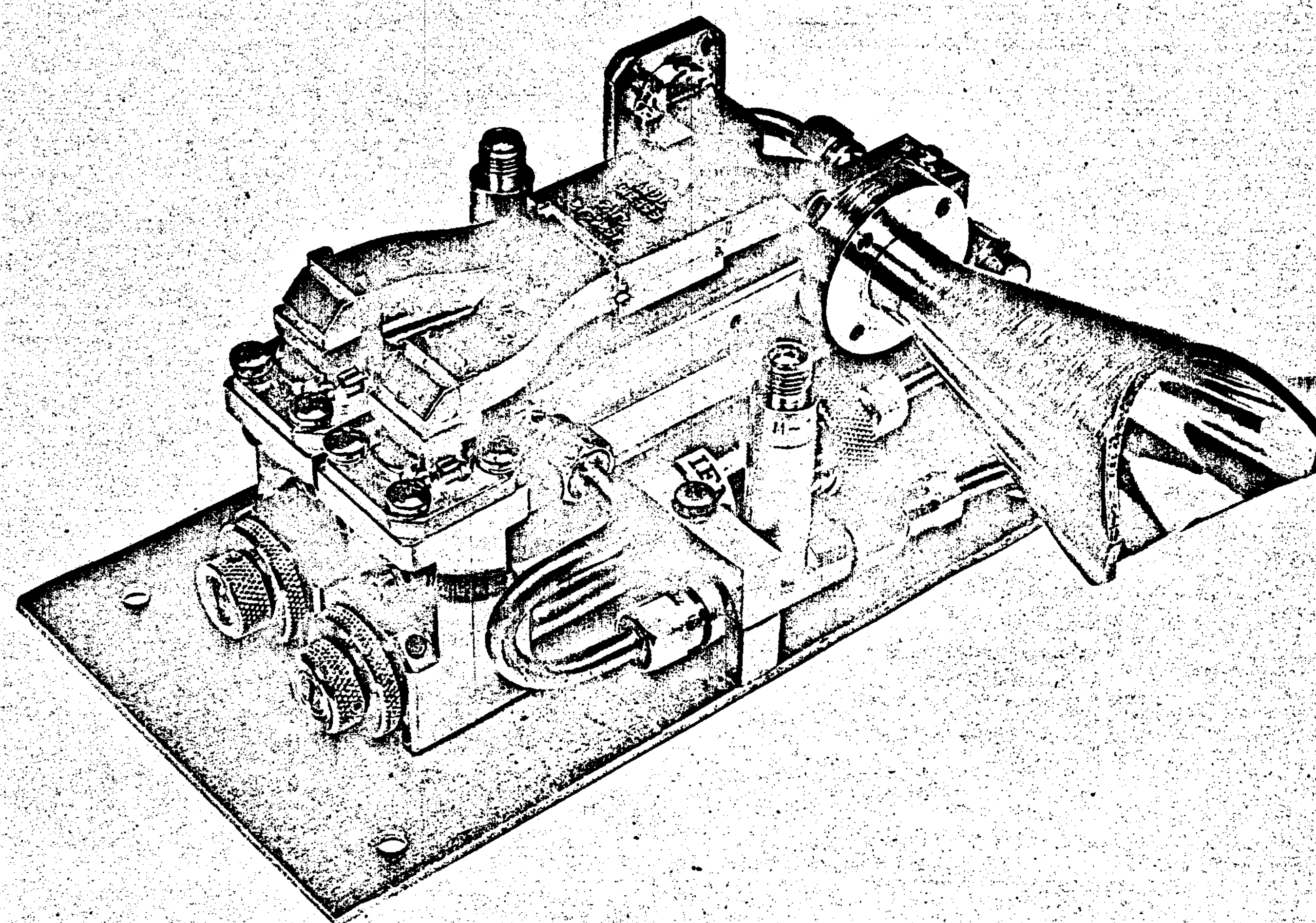

Figure 3. Engineering Model of Spacecraft Balanced Mixer and Receiving Antenna for 31.65 GHz.

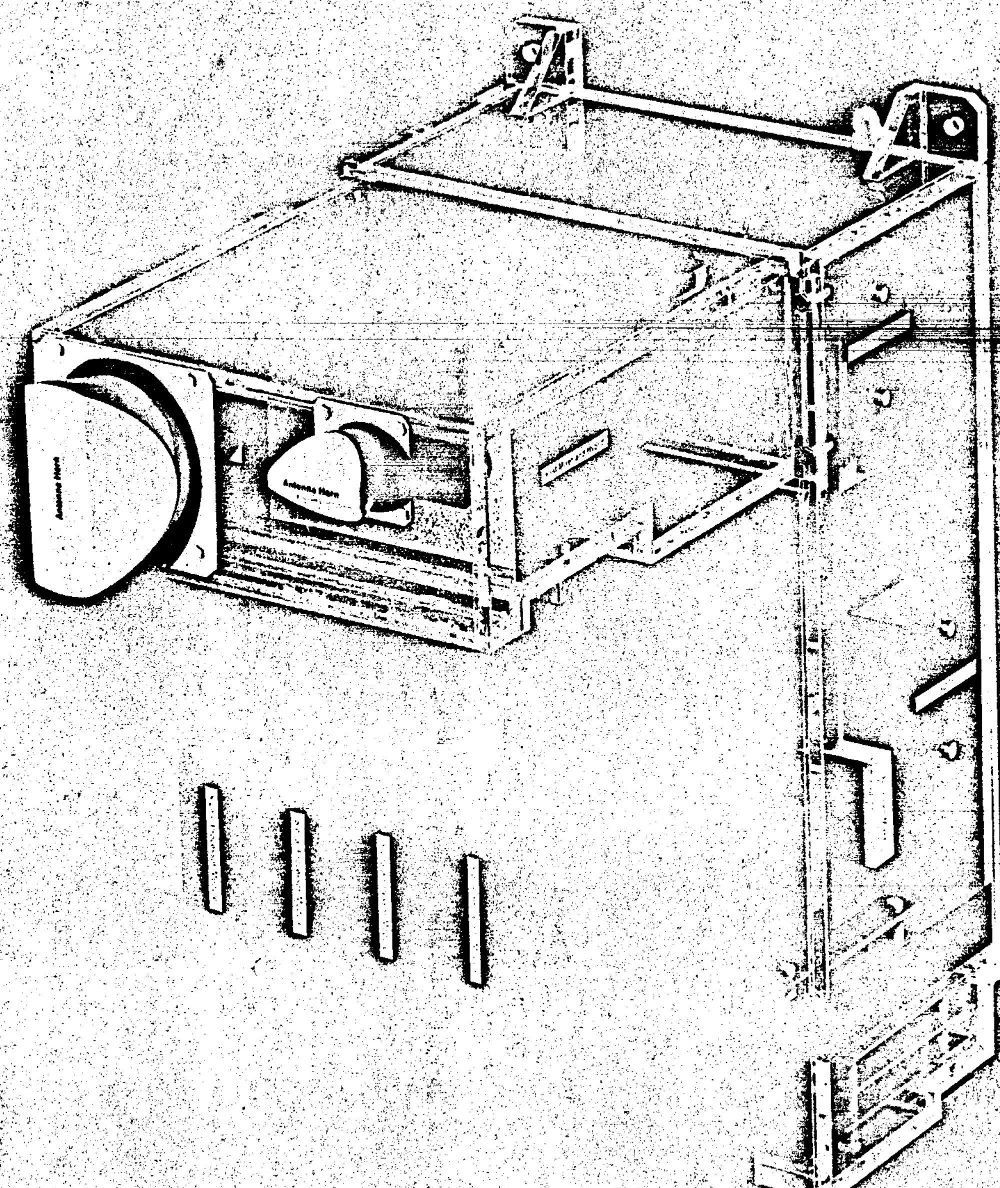

Figure 4. Photograph of Satellite Equipment for the Millimeter-Wave Experiment